Future $\bar{p}$ Opportunities

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Brighter Booster Physics Workshop
6 June 2001
and
Fermilab Proton Driver Workshop
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My main topics today:

- I will hit some "personal" highlights:

  Hyperon beta decay

  Hyperon CP violation

- **Also relevant:**

  Charmonium studies (covered by Gollwitzer)

  Search for glueballs/exotics

  Physics with trapped $\overline{p}$s (*e.g.* antihydrogen)

→ See *$\overline{p}$2000* Proceedings for more detail

$\bar{p}$2000 Workshop Motivation(s):

- Fermilab starting to define directions for post-LHC era
  $\rightarrow$ broadening the program could be appealing if sufficient clientele
- Fermilab has highest-intensity $\bar{p}$ source and intensity will increase
- $\bar{p}p \rightarrow$ charmonium,hyperons: Chang/Valencia/Hertzog/Swallow/Seth
  $\rightarrow$ improved luminosity & cooling could improve the physics
- $\bar{p}p \rightarrow$ light-quark resonances: Wiedner/Page/Bugg
  $\rightarrow$ could more data clarify glueball & hybrid puzzles?
- Trapped $\bar{p}$: more beam, better duty factor than AD Holzscheiter/Phillips
  $\rightarrow$ explore new techniques and ideas?

$\Rightarrow$ **Can physics motivation plus technical improvements yield a vigorous $\bar{p}$ program at Fermilab?**

Physics Examples:

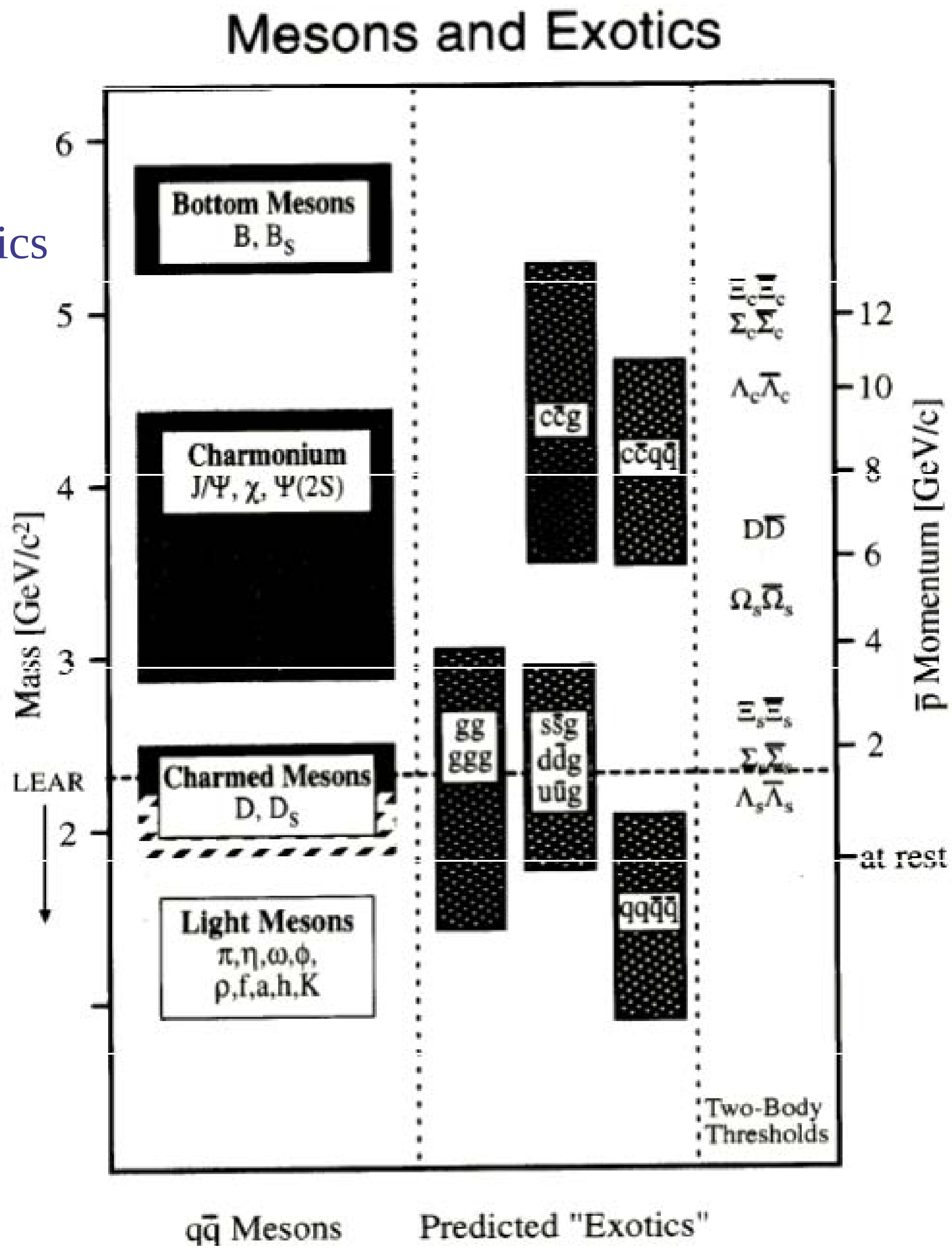
1. Search for glueballs & exotics
   (U. Wiedner, Uppsala)

2. Hyperon CP violation
   (DMK)

3. Hyperon beta decay
   (N. Solomey, IIT)

4. Charmonium
   (K. Seth, NWU)

5. Trapped-antiproton physics
   (M. Holtzscheiter, LANL)



LEAR glueball search

Isoscalar 0^{++} resonances seen by Crystal Barrel

		Decay mode
$f_0(975)$:	$M = 980 \pm 20$ MeV	$\pi\pi$
	$\Gamma = 100 \pm 20$ MeV	
$f_0(1370)$:	$M = 1365 \pm 50$ MeV	$\pi\pi$ $\eta\eta$ 4π
	$\Gamma = 270 \pm 80$ MeV	
$f_0(1500)$:	$M = 1511 \pm 8$ MeV	$\pi\pi$ $\eta\eta$ $\eta\eta'$
	$\Gamma = 116 \pm 17$ MeV	$K\bar{K}$

\+ other experiments:

$f_0(1450)$:	$M = 1446 \pm 5$ MeV	4π
	$\Gamma = 56 \pm 12$ MeV	
$f_0(1590)$:	$M = 1581 \pm 10$ MeV	$\eta\eta'$ $\eta\eta$ 4π
	$\Gamma = 180 \pm 17$ MeV	
$f_0(1525)$:	$M = 1525$ MeV	$K\bar{K}$
	$\Gamma = 90$ MeV	
$f_J(1710)$:	$M = 1709 \pm 5$ MeV	$K\bar{K}$ $\pi\pi$
	$\Gamma = 140 \pm 12$ MeV	

Too many resonances

Interpretation of the results:

$f_0(975)$, $a_0(980)$:	KK-molecules
$f_0(1370)$:	Nonet member
$f_0(1525)$, $f_J(1710)$:	Nonet member
$f_0(1500) = f_0(1590) = f_0(1450)$:	Exotic

- Conclude:
  - – Already much evidence for gluonic exotics, but low-mass region confusing
  - – Most exotics predicted above LEAR kinematic limit, that's where signatures will be cleanest

⇒ Want higher-energy storage ring than LEAR or Accumulator → GSI?

Hyperon Beta Decay

- Some outstanding questions:

  1) V_{us} measured in various hyperon and kaon beta decays inconsistent [N. Solomey, Proc. $\bar{p}$*2000* Workshop]:

Decay	V_{us}	Uncertainty
$K_L^0 \to \pi^+ e^- \nu$	0.2188	± 0.0016
$\Lambda^0 \to p\, e^- \nu$	0.2130	± 0.0020
$\Sigma^- \to n\, e^- \nu$	0.2318	± 0.0040
$\Xi^- \to \Lambda^0 e^- \nu$	0.2434	± 0.0068

  – just soft hadronic physics? or...

  2) Possible existence of "2nd-class" weak currents – measurable in hyperon beta-decay form factors

  3) Possibility of Λ–Σ^0 mixing – postulated, never confirmed

- Could effects 2), 3) reconcile discrepancy 1)? [Donoghue et al.]

- These studies require much larger samples than now available

HYPERON CP VIOLATION

- **Parity violating, ΔS = 1 decay of a spin-$\frac{1}{2}$ strange baryon into a spin-$\frac{1}{2}$ baryon and a pion, e.g.**

$$\Lambda \to \mathrm{p}\,\pi$$

is described by the decay amplitude

$$\mathcal{M}(\Lambda \to \mathrm{p}\,\pi) = S + P\,\vec{\sigma} \cdot \widehat{q}_p$$

S **is the amplitude of the S-wave final state**
P **is the amplitude of the P-wave final state**
$\widehat{q}_p$ **is the momentum unit vector of the proton**

- **In the rest frame of the Λ the angular distribution of the proton**

$$\frac{dn}{d\Omega} = \frac{1}{4\pi}(1 + \alpha_\Lambda \vec{\mathcal{P}}_\Lambda \cdot \hat{q}_p)$$

where $\vec{\mathcal{P}}_\Lambda$ is the polarization of Λ and the decay parameter α is defined as

$$\alpha_\Lambda = \frac{2Re(S^* P)}{|S|^2 + |P|^2}$$

- **If CP is conserved**

$$\alpha_{\overline{\Lambda}} = -\alpha_\Lambda$$

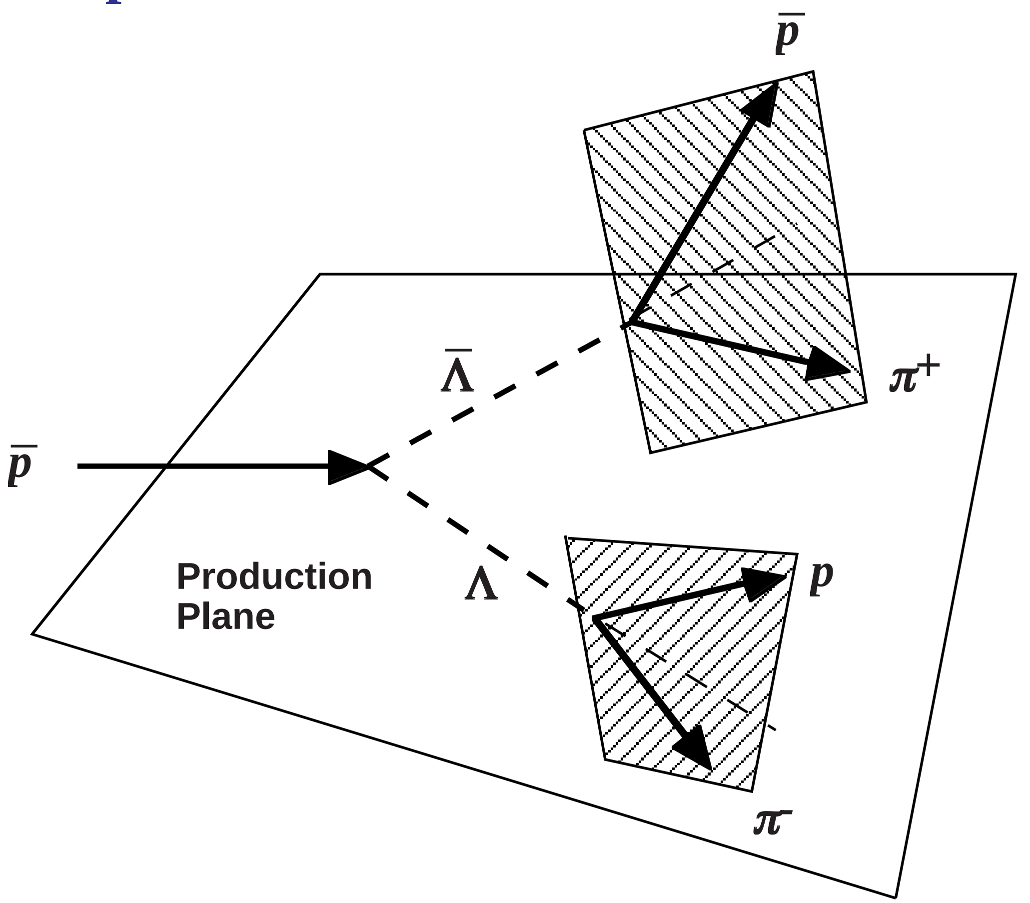
- **One can form a CP violating asymmetry**

$$A_\Lambda = \frac{\alpha_\Lambda + \alpha_{\overline{\Lambda}}}{\alpha_\Lambda - \alpha_{\overline{\Lambda}}}$$

- **Complementary to ε'/ε**

A_Λ ACCESSIBLE IN $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$:

- Compare numbers of decays in which both p and $\bar{p}$ above production plane vs. both below



- Events with p above, $\bar{p}$ below and vice versa provide systematics check

Brief History:

- PS185 at LEAR proposed 1981, begins 1984
- $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ proposed for CP: Donoghue, Holstein, Valencia, He, Pakvasa, 1986
- CERN Hyperon CP study group: technique feasible @ 10^{-4} statistics (SuperLEAR), 10^{-5} systematics
- Hsueh and Rapidis propose new $\bar{p}$ storage ring at Fermilab (P859, 1992) $\rightarrow$ rejected
- LEAR shut down 1996, PS185 ends
- Published PS185 limits:

$A_\Lambda = 0.013 \pm 0.022$ [P. D. Barnes *et al.*, Phys. Rev. C **54,** 1877 (1996)]

Latest: 0.006 ± 0.015 [P. D. Barnes *et al.*, Nucl. Phys. B (Proc. Suppl) **56A,** (1997) 46]

Now superseded by newer Fermilab high-energy technique:

- HyperCP (FNAL E871) proposed 1994, ran 1997 & 1999

THEORY & EXPERIMENT

Theory

- **SM:** $A_\Lambda \sim 10^{-5}$
- **Other models:** could be several $\times 10^{-4}$ [*e.g.* SUSY ε′/ε: X.-G. He *et al.*, Phys. Rev. D **61** , 071701 (2000)]

Experiment	Decay Mode	A_Λ	Year
R608 at ISR	$pp \to \Lambda X, \bar{p}p \to \bar{\Lambda} X$	-0.02 ± 0.14	1985
DM2 at Orsay	$e^+e^- \to J/\Psi \to \Lambda\bar{\Lambda}$	0.01 ± 0.10	1988
PS185 at LEAR	$p\bar{p} \to \Lambda\bar{\Lambda}$	0.006 ± 0.015	1997

Experiment	Decay Mode	$A_\Xi + A_\Lambda$	Year
E756 at Fermilab	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	0.012 ± 0.014	2000
E871 at Fermilab (HyperCP)	$\Xi \to \Lambda\pi, \Lambda \to p\pi$	$\pm \approx 1.4 \times 10^{-4}$	

E871 (HyperCP) Collaboration

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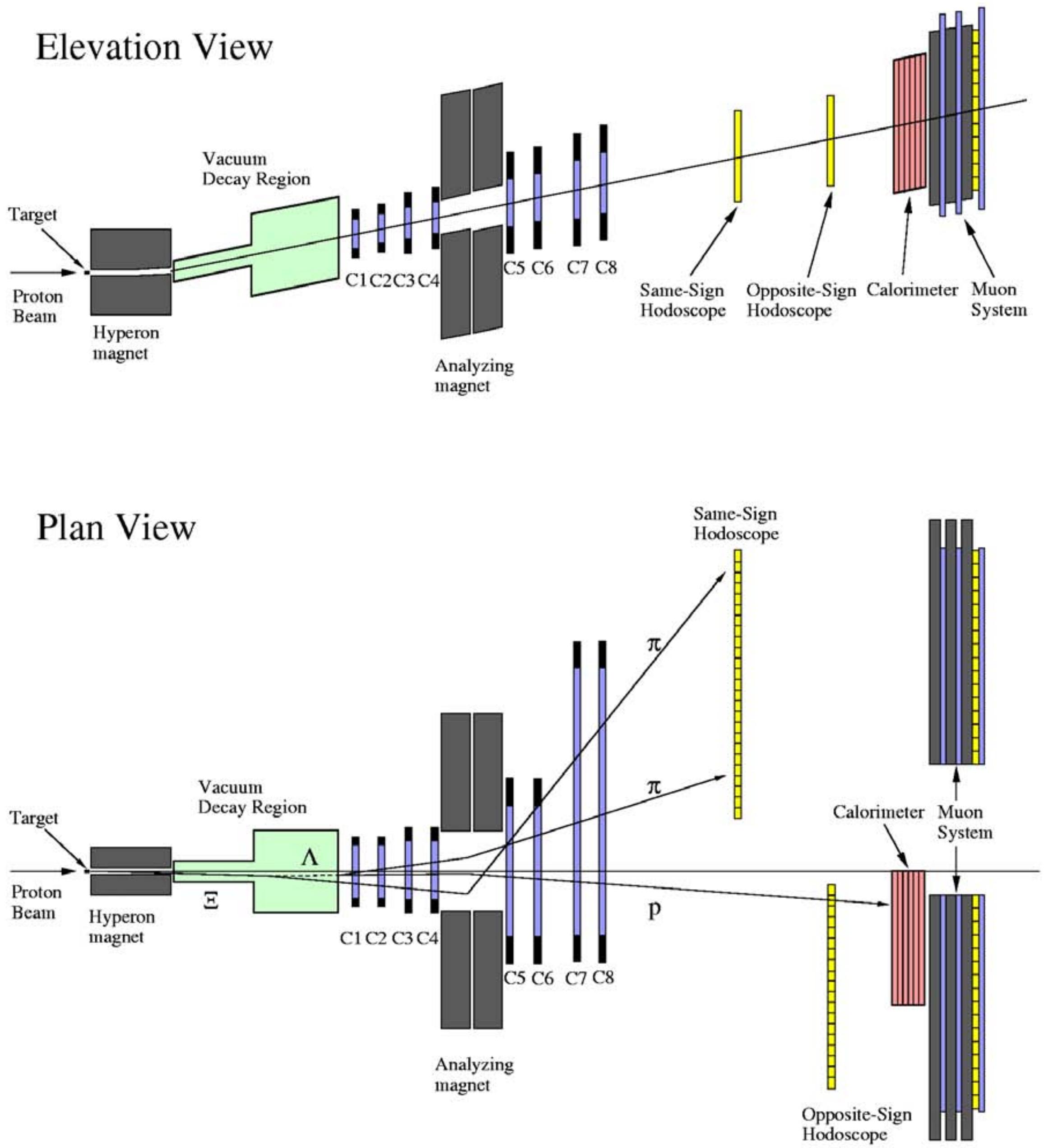
HYPERCP SPECTROMETER



SUMMARY OF THE 1997 and 1999 RUNS

	1997 Run	1999 Run
Number of tapes	9,376	18,838
Data Volume	38 TB	71 TB

Projected number of reconstructed events

Ξ^-	2×10^9
$\overline{\Xi}^+$	0.5×10^9
K^+	0.32×10^9
K^-	0.13×10^9
Ω^-	14×10^6
$\overline{\Omega}^+$	5.3×10^6

$$\delta(A_{\Xi\Lambda}) \; = \; 1.4 \times 10^{-4} \text{ statistical precision}$$

Can hyperon-beam approach be extended to 10^{-5}?

- Clearly hard:

  1. 20-MHz 2ndary-beam rate → 2 GHz???
     HyperCP limit was ≈1% chamber inefficiencies in beam region

  2. No more 800-GeV fixed-target!

- But maybe not impossible?

  1. MI FT has ~10 × 800-GeV duty factor?
     ⇒ 2ndary-beam rate → 200 MHz?

  2. But systematic feasibility not established at (say) $E_{2ndary} \approx 80$ GeV

→ Important: E-dependent $p/\overline{p}$, π^+/π^- cross-section differences get worse at lower E (but note that they tend to cancel)

Consider new $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ exp't:

- Sensitivity estimate (p_{beam} = 1.64 GeV/c):

	L	pbars/hr	tgt density	I_pbar	N_pbar	days @50%	events	CP reach
	/cm^2/s		A/cm^2	mA				
P859:	1.6E+32	5.8E+10	1.0E+14	256	8.0E+11	88	2.3E+09	1.0E-04
	1.0E+33	3.6E+11	3.0E+14	533	1.7E+12	365	5.9E+10	2.0E-05
xP859:		6.3					26	5.1

$\Rightarrow 10^{-5}$ not necessarily crazy –

...especially with Brighter Booster

- BUT: need to establish
  - rate capability of detector, trigger, DAQ
  - whether $<10^{-5}$ systematics feasible, *e.g.* suppose $p_{beam} \rightarrow 1.7$ GeV/c: symmetrizes Λ, $\bar{\Lambda}$ momenta and angles, but brings $\bar{p}p \rightarrow \bar{\Lambda}\Sigma$, $\Lambda\bar{\Sigma}$ contamination...

$\Rightarrow$ more work needed!

Luminosity and stacking rate

- Need 10^{33} for CP experiment, 10^{32} sufficient for other physics
- Stacking rate:
  - Current "state of the art":

    10 mA/hr $\Rightarrow 10^{11}\ \bar{p}$/hr

    $\Rightarrow \mathcal{L} \lesssim 2 \times 10^{32}/\mathrm{cm}^2/\mathrm{s}$
  - Goals:

    20 mA/hr Start of Run II

    100 mA/hr Run IIB (~2005)
    using e^- cooling in recycler
    could support $\mathcal{L} \sim 10^{33}/\mathrm{cm}^2/\mathrm{s}$ plus Tevatron experiments

Conclusions

- I believe there is strong physics interest in a dedicated $\overline{p}$ facility at Fermilab
- A facility including a ≈2-GeV/c ring plus a 1–10-GeV/c ring would serve a diverse community of particle, nuclear, and atomic physicists (not to mention medical etc. applications)
- Brighter Booster important in allowing such a program to achieve luminosity goals while coexisting with other proton users
- We need to do the design and simulation work to establish feasibility of various physics targets

$\bar{p}$*2000* Workshop

- International workshop held at Illinois Institute of Technology (IIT), Chicago, IL, USA Aug. 3–5, 2000

  → http://www.iit.edu/~bcps/hep/pbar2000.html

- 39 participants from

Argonne National Lab.	US
Duke Univ.	US
Elmhurst College	US
Fermilab	US
GSI Darmstadt	Germany
IIT	US
Indiana Univ. Cyclotron Facility	US
INFN Genova	Italy
Los Alamos National Lab.	US
National Tsing-Hua Univ.	Taiwan
Northwestern Univ.	US
Rutherford Appleton Lab.	UK
Ruhr-Univ. Bochum	Germany
Univ. Illinois Urbana-Champaign	US
Univ. Ferrara	Italy
Univ. Genova	Italy
Univ. Mississippi	US
Uppsala Univ.	Sweden

- Major questions:

  1. What will be Fermilab's capabilities in $\bar{p}$ physics during the next several years?
  2. Can a strong physics program be identified to take advantage of these capabilites?

  → See $\bar{p}$*2000* Proceedings (all papers available at http://www.capp.iit.edu/~capp/workshops/pbar2000/papers/)